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Asymmetric-Cladding 1480-nm Pump Laser With CW Fiber Output Power of 1 W

Yasuaki Nagashima, Shinichi Onuki, Yoshiharu Shimose, Atsushi Yamada and Tomoyuki Kikugawa
Research Laboratory, Anritsu Corporation, 1800 Onna, Atsugi-shi, Kanagawa 243-8555, Japan
Nagashima.Yasuaki@jj.anritsu.co.jp

Abstract: We have proposed high slope efficiency 1480-nm pump laser with asymmetric waveguide structure employing n-InGaAsP cladding layer instead of conventional InP cladding layer. We have achieved LD chip output power of more than 1.1W at 4A with fundamental lateral mode condition. We have also achieved excellent single-mode fiber coupling efficiency and fiber output power of 1W.
OCIS codes: (140.2020) Diode Lasers; high-power, pump lasers

Introduction

High-power 1480-nm semiconductor lasers operating in the fundamental lateral mode are attractive candidates for erbium doped fiber amplifier (EDFA) and Raman amplifiers. Several approaches have been reported to improve output optical power [1-3]. A significant problem is the degraded slope efficiency with increased cavity length. Reduction of internal loss is very effective to overcome this degradation which is caused by inter valence band absorption (IVBA) in the p-cladding layer. We have proposed adoption of an asymmetric cladding layer structure to decrease internal optical loss caused by IVBA in the p-cladding layer [4]. In this work we demonstrate that asymmetric cladding LD achieved the excellent fiber coupling efficiency of 92 % and single-mode fiber output power of 1W.

Concept and Design

In prior work, we tried weakening the optical confinement in the active layer by optimizing the thickness and refractive index of each layer forming the optical confinement layer (OCL) to reduce the internal loss, α_i. However, weak optical confinement allows the evanescent field of the guided wave to expand into the cladding layers, resulting in increased internal loss due to IVBA in the p-side cladding layer.

In recent work, we have used an asymmetric waveguide structure with a slightly higher refractive index at the n-side cladding layer consisting of quaternary compound than at the p-side InP cladding layer. This asymmetric structure is effective in improving the output power for three reasons:

1. Internal loss due to IVBA in the p-cladding layer is substantially reduced by a shift in the guided wave field distribution to the n-cladding direction.
2. Introduction of a higher index cladding layer decreases the equivalent refractive index difference of the waveguide, resulting in expansion of the maximum stripe width that cuts off the higher lateral mode.
3. The field distribution shift effectively lowers resistance, because a relatively small part of the field distribution in the p-cladding layer reduces the effect of the p-doping concentration. This permits optimization of the concentration and p-cladding layer thickness for the resistance reduction.

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We investigated the effect of asymmetric structure using an n-InGaAsP cladding layer and optimized the InGaAsP composition using the beam propagation method. Figure 1(a) shows the simulation model. The simulation parameters, such as refractive indices and thicknesses are based on the conventional optimized structure using n-InP cladding. We calculated the propagation mode using the refractive index of n-InGaAsP as a variable parameter. When designing the asymmetric structure, care was taken to maintain the fundamental lateral mode and a sufficient asymmetric field distribution. As a result, we used an InGaAsP cladding layer with a bandgap wavelength of 0.95 μm (Q095). Figures 1(b) and (c) show the field distribution for Q095 and InP cladding, respectively. For InP cladding, the optical confinement factors to the active layer and p-cladding layer are about 16 %, and 42 %, respectively. For Q095 cladding, the factors are 13 % and 25 %, respectively. Consequently, the part of the field distribution in the p-cladding layer becomes almost half. Furthermore, the cut-off stripe width for the Q095 cladding structure can be expanded from 3.5 μm (which is optimized for the conventional InP cladding structure) to about 5.0 μm.

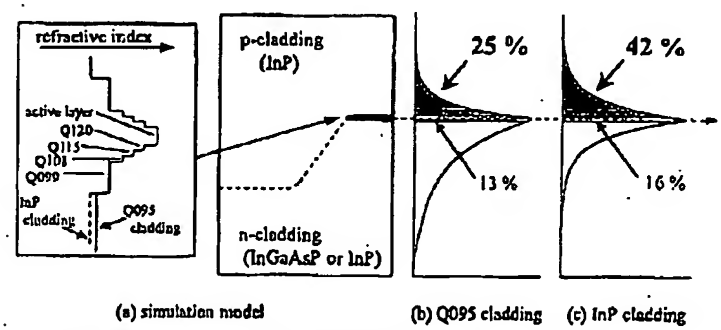


Fig.1 Simulation model and calculated field distribution for Q095 and InP cladding

Device structure

Figure 2 shows the schematic structure of the fabricated LD and refractive indices profile in the vicinity active region. The structure was fabricated by a three-stage MOVPE growth process and wet-chemical mesa etching on n-InP substrate. The thickness of the n-Q095 cladding layer is 7.5 μm, which is designed to be an enough thickness for a guided wave not to be influenced by the InP substrate. The MQW structure consists of four +1 % compressively strained InGaAsP quantum-wells and unstrained InGaAsP barriers. The OCL consists of three InGaAsP layers with respective bandgap wavelengths of 0.99, 1.08 and 1.15 μm. The composition and thickness of both OCLs are symmetric for active region. The width of the active region is 5.0 μm and the LD cavity length is 2.3 mm or 3.0 mm. We also fabricated a conventional n-InP cladding-type LD (L = 2.3 mm) with an active-region width of 3.5 μm. The front and rear facets of all devices were coated with low-reflection (LR) and high-reflection (HR) coatings, respectively. The value of each LR has been optimized so that an saturation output power may become the maximum. All devices were bonded on diamond heat sinks with p-side down.

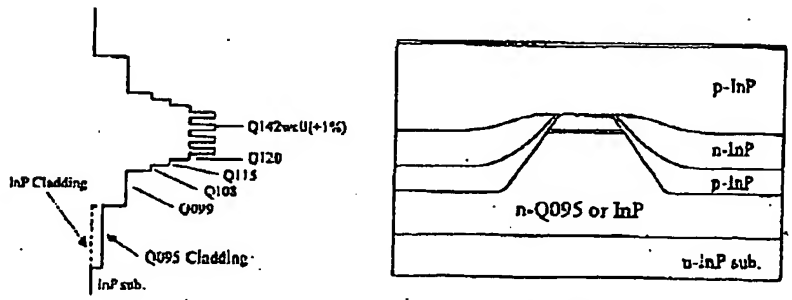


Fig.2 Schematic structure of asymmetric-cladding laser

Result and Discussion

The output power and voltage characteristics for the asymmetric-cladding LDs with cavity lengths of 2.3 mm and 3 mm versus the drive current are shown in Fig. 3, along with the conventional InP cladding-type LD with a cavity length of 2.3 mm for comparison. All characteristics were measured at a heat-sink temperature of 25 °C. An extremely high slope efficiency of 0.467 W/A is obtained for the asymmetric-cladding LD with a cavity length of 2.3 mm; the efficiency for the conventional InP-cladding LD is about 0.4 W/A. We estimated the value of α_i for the asymmetric-cladding LD as 3.0 cm^{-1}, which we believe is a record low for 1.48-μm pump lasers. On the other hand, the value of α_i for the InP-cladding LD was 4.5 cm^{-1}. We confirmed that internal loss in an actual device is suppressed by the asymmetric cladding structure. Furthermore, widening of the stripe width up to 5.0 μm reduces the device resistance and increases the saturation current. Even when the cavity length is 3 mm, the slope efficiency remains at a relatively high value of 0.450 W/A. As a result, we achieved a maximum LD output power of more than 1.1 W at 4 A.

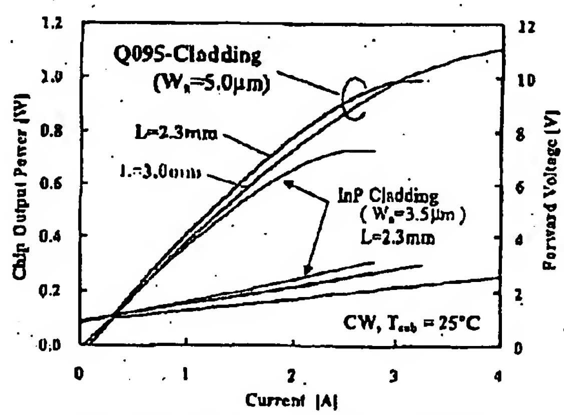


Fig.3 L-I and V-I characteristics for Q095 or InP Cladding LD

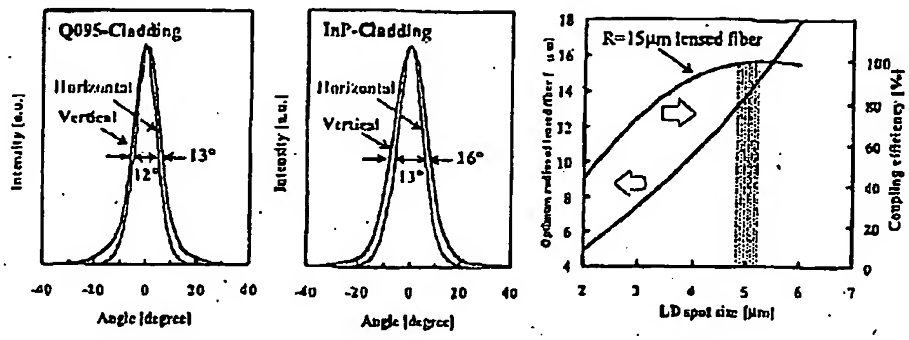
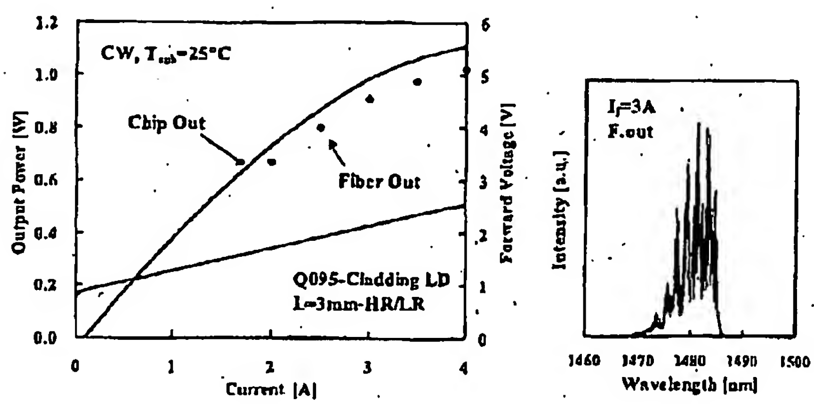


Fig.4 Far field patterns for Q095 and InP cladding (I_f =2A)

Fig.5 Simulation result of coupling efficiency for tapered lensed fiber

Figure 4 shows the far field patterns (FFPs) for both types of LD at 2 A. As shown, the higher-order lateral modes are suppressed although the active region was widened up to 5.0 μm. By using the Q095 n-cladding layer, both FWHMs of the vertical and horizontal FFP became small and similar values of about 13°. The reduction of beam divergence, especially for the vertical direction, indicates that the introducing of the Q095 cladding layer extends the field distribution to the n-cladding side effectively. It is possible to obtain high coupling efficiency by direct-coupling (without lenses) in case that LDs have such a large spot size and nearly circular beam profile.



(a) L-I, V-I Characteristics

(b) lasing spectrum

Fig.6 Experimental result of fiber coupling

Figure 5 shows the optimum radius of curvature (R) of a tapered lensed fiber corresponding to a spot size of LD. The spot size value for the asymmetric-cladding LD estimated from fig. 4 is about 4.8 ~5.2 μm. Therefore, the optimum radius of a lensed fiber corresponding to this spot size is around 14 μm. Figure 5 also shows optical coupling efficiency of the lensed fiber with R=15 μm as a function of a spot size of LD. We can expect coupling efficiency of almost 100% with R=15 μm lensed fiber which was available easily. Figure 6 shows a experimental result of fiber coupling on the optical bench. The LD with cavity length of 3 mm was used for the experiment. In fig. 6 (a) the solid line shows the chip output characteristics, which is the same as the one shown in fig. 3, and the dots shows R=15 μm lenzed fiber output power. The coupling efficiency was about 92%, which agrees fairly well with the calculated coupling efficiency. As a result, the maximum fiber output power was achieved 1 W. The lasing spectrum at drive current 3 A is shown in fig. 6 (b). The center of the lasing wavelength is 1480 nm and there is no observable degradation in the spectrum.

Conclusion

We have developed a high power 1480-nm pump laser diode with an asymmetric waveguide structure using an n-Q095 cladding layer, which enables low internal loss and high slope efficiency. We have achieved a chip output power of 1.1 W at 4 A with a 3-mm long cavity laser. Furthermore, since this LD has nearly circular beam profile and large spot size, superior coupling efficiency of 92% was achieved by using a simple single-mode lensed fiber (R=15 μm). As a result, we have realized the maximum fiber output power of 1W under CW operation at 25 °C.

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